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TECHNICAL NOTE

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ON THE BREAKDOWN VOLTAGES OF SOME ELECTRONEGATIVE GASES AT LOW PRESSURES

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SUMMARY

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The breakdown voltages of five Freon gases and SF_6 were measured at low pressures between parallel plates to determine their insulating properties under these conditions, and especially to find their minimum breakdown voltages. It was found that the advantages of these gases over air are much less at low pressures than at atmospheric pressure or higher and that the use of these gases as insulators at low pressures is therefore limited. Preliminary investigations revealed, however, that the vapors of compounds that are liquid at normal temperature and pressure, such as FC-75, maintain their dielectric strength much better than do electronegative gases as the pressure is reduced, and thus seem to be promising for use as insulators at low pressures.

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INTRODUCTION

Certain artificial earth satellites, with direct-current power supplies in the range of 1600 to 2000 volts, have difficulties caused by corona-type discharges at altitudes of about 100,000 feet. These difficulties occur because the equivalent pd (p is the pressure, and d the distance between electrodes) in the satellites passes through the range of minimum breakdown voltage, which in air is about 350 volts. No difficulties occur at either higher or lower altitudes, as might be expected from Paschen's Law, which states that the breakdown voltage between two electrodes is a function of the pressure times the distance between the electrodes and decreases with this product down to a certain minimum, after which it rises again as pd decreases further.

The exact shape and location of the curve of pd versus breakdown voltage will depend on the shape of the electrodes, the material of which they are made, and the nature of the dielectric between them.

Various suggestions for preventing corona-type discharges in the satellites have been made. The solution presently in use consists of imbedding all electrodes (charged conductors) in a solid dielectric so that gaseous discharges are impossible. This is disadvantageous in that conductors, once imbedded, are difficult to remove. Other possibilities include using electronegative gases as insulators (the subject of the present investigation), pressurizing high voltage components, immersing these components in oil, evacuating the entire system, keeping the power off until the critical values of pd have been passed (delayed switching), and artificially suppressing the free electrons in the gas. Some of these suggestions may well bear further investigation. Other possible avenues of investigation are the seeking of improved design criteria to delay corona and the further study of the effects of electrode materials and configurations, not only to prevent, if possible, the onset of corona but also to provide the designer with improved methods of predicting when corona may occur.

To solve the satellite problem, it was proposed to enclose the high voltage components in an electronegative gas that would be allowed to leak out as the satellite rose, so that the pressure inside the satellite would remain about the same as the pressure outside. This would eliminate the need for

*Work performed at Goddard Space Flight Center as part of the 1962 Summer Workshop Program. Also to be published in the Transactions of the American Institute of Electrical Engineers.
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pressurization and the danger of unintentional leaks, and would prevent corona-type discharges as long as the minimum breakdown voltage of the gas was higher than the maximum voltage expected in the satellite. For this reason, a study was undertaken to find the minimum breakdown voltages of certain electronegative gases.

PREVIOUS WORK ON ELECTRONEGATIVE GASES

It is well known that electronegative gases obtain their dielectric strength from the fact that thei: molecules have a tendency to absorb loose electrons and thus inhibit the electron avalanches necessary for breakdown. This already has been discussed briefly by Meek and Craggs in Reference 1. A somewhat longer summary is given by Devins and Sharbaugh in Reference 2. The effect of pressure on the positive point-to-plane discharge for some electronegative gases was investigated in 1939 by Pollack and Cooper (Reference 3). After the war, further investigations were undertaken by Camilli and Chapman (Reference 4) and Wilson et al. (Reference 5). Further work was done on fluorine-containing gases by Camilli and Plump in 1952 (Reference 6). Additional theoretical considerations were published by Geballe and Reeves in 1953 (Reference 7). The electric breakdown of perfluorocarbon vapors and their mixtures with nitrogen was investigated by Berberich et al. in 1955 (Reference 8); the dielectric behavior of some fluorogases and their mixtures was also discussed in the same year by Camilli et al. (Reference 9). Further study of factors controlling electric strength of gaseous insulation was done by Narbut et al. in 1959 (Reference 10). The advantages of gas-insulated power transformers were presented by Camilli in 1959 (Reference 11). In the same year Blodgett evaluated some of the dielectric properties of octafluorocyclobutane (Reference 12). A further discussion of fluorocarbons as electrical insulators was given by Reuther in 1951 (Reference 13).

The above is by no means a complete listing but is given merely as an illustration of some of the work that has been done in this field. Further references may be found in AIEE Special Publication S-97 (Reference 14). The difficulty with most of the previous work is that it was concerned chiefly with the insulating properties of gases at atmosphere or higher pressures; very little has been said about breakdown at lower pressures and especially about minimum breakdown voltages.

GASES CONSIDERED IN THE PRESENT STUDY

The gases considered in the present study were Freons 14, 114, 115, 116, C318, and SF_6. Sulfurhexafluoride (SF_6) was chosen because it is perhaps the best known and most used of the electronegative gases. The newer Freons were evaluated because little is as yet known about their properties and it was hoped that they would prove superior to their older "relatives."

Freon 14 is tetrafluoromethane, CF_4. It has a molecular weight of 88.01, boils at -128°C, and freezes at -184°C at 1 atmosphere pressure. Its dielectric strength at 1 atmosphere and 23°C relative to nitrogen is 1, and its dielectric constant is 1.0006 at 24.5°C and 1 atmosphere.

Freon 114 is dichlorotetrafluoroethane $CClF_2-CClF_2$. It has a molecular weight of 170.93, boil at 3.55°C, and freezes at -94°C at 1 atmosphere pressure. Its dielectric strength relative to nitrogen is 2.8 at 1 atmosphere and 23°C, and its dielectric constant is 1.0021 at 26.8°C and 1 atmosphere

Freon 115 is chloropentafluoroethane, $CClF_2$-CF_3. It has a molecular weight of 154.48, boils at -38 °C, and freezes at -106 °C at 1 atmosphere pressure. Its dielectric strength relative to nitrogen is 2.8 at 1 atmosphere and 23° C, and its dielectric constant is 1.0018 at 27.4 °C and 1 atmosphere.

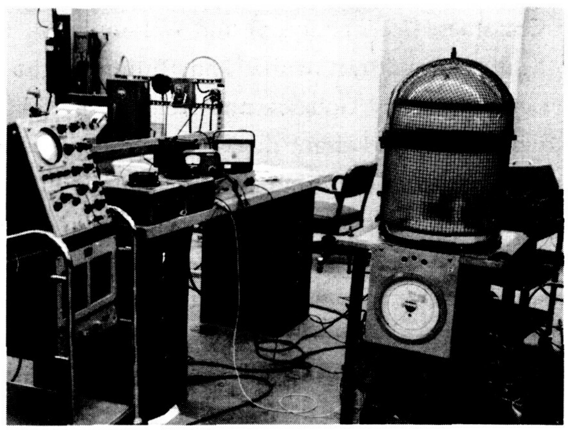
Freon 116 is hexafluoroethane, C_2F_6. It has a molecular weight of 138.0, boils at -78.2 °C and freezes at -100.6 °C at 1 atmosphere pressure. Its dielectric strength relative to nitrogen is 1.96 at 1 atmosphere, and its dielectric constant is 1.00197 at 23° C and 711 mm Hg.

Freon C318 is octafluorocyclobutane, C_4F_8 (cyclic). It has a molecular weight of 200, boils at -6.0 °C, and freezes at -41.4° C at 1 atmosphere pressure. Its dielectric strength relative to nitrogen is 2.63 at 1 atmosphere, and its dielectric constant is 1.0034 at 10° C and 760 mm Hg.

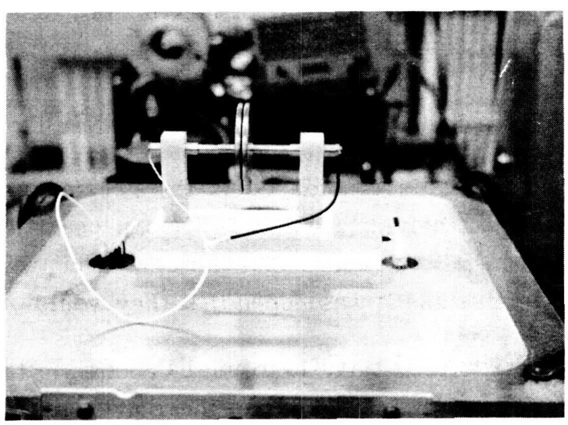
The properties of *sulfurhexafluoride,* SF_6, are well known. Its molecular weight is 146, it boils at -63.8° C at 1 atmosphere pressure, and its dielectric strength relative to nitrogen is 2.5 at 1 atmosphere.

THE EQUIPMENT USED

The equipment used was a variant of that used by Dakin and Lim (Reference 15) of Westinghouse and that of E. L. Brancato of the Naval Research Laboratory (Figures 1 and 2). Two parallel circular brass plates, 4 inches in diameter and 1/4 inch thick with rounded edges of 1/8 inch radius, mounted on a Teflon base, were used as electrodes. These were connected to a 3000 volt transformer connected to an ordinary 60 cycle, 110 volt power supply. The 60 cycle alternating current, while yielding the same type of corona as direct current, has the advantage over direct current that, because of its relatively slow oscillations, it triggers corona at each peak of the cycle on a regular basis at the proper voltage—and thus makes it much easier to study the phenomenon (Figure 3). Filters were used both to suppress high frequency noise from the power supply before it reached the electrodes and to filter out the 60 cycle sine wave before feeding the signal to the oscilloscope. The presence of corona was determined by observing the signal from the electrodes on a Tektronix type 545A oscilloscope, using a type L plug-in unit preamplifier with a fast rise time.



(a) Total setup showing scope, variacs, vacuum gage, voltmeter, bell jar, and pressure gage



(b) The electrodes

Figure 1—Experimental equipment for determining breakdown voltage of electronegative gases.

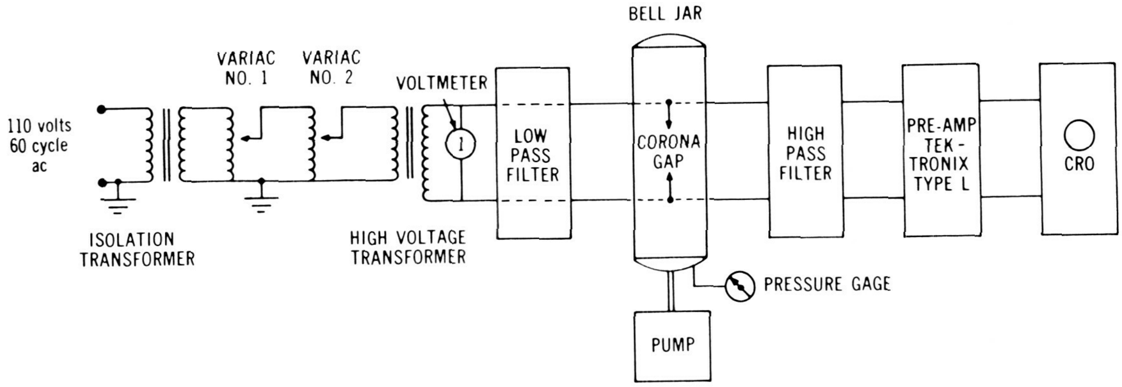
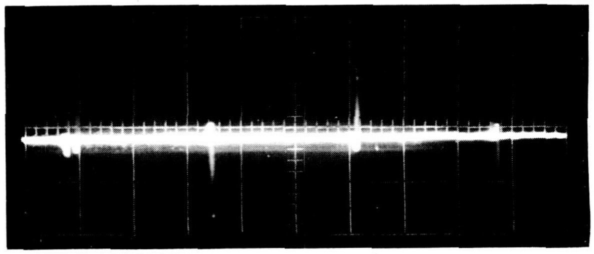
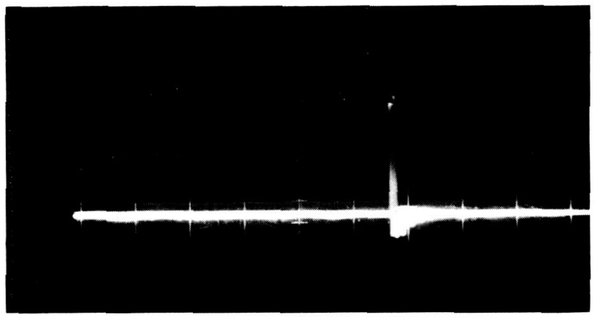


Figure 2 - Experimental equipment.

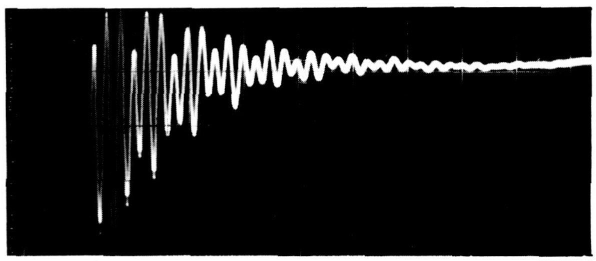
The electrodes themselves were placed in a bell jar that was evacuated by means of a mechanical pump capable of reducing the pressure in the bell jar to 45 microns Hg. Voltages across the electrodes were read from a carefully calibrated Simpson vacuum-tube voltmeter. The pressure inside the bell jar was read from a Wallace and Tierney absolute-pressure gage calibrated to read NACA 1956 standard atmosphere to 200,000 feet; from 1 mm Hg down, the pressure was also read from a Consolidated Vacuum Corporation thermocouple vacuum gage to give a double check in the range of equivalent altitude from about 150,000 to 200,000 feet. The filters were immersed in transformer oil to prevent the possibility of local discharges occurring in the circuit.



(a) Corona discharges being triggered by 60 cycle sine wave



(b) Single corona pulse, showing initial spike (double exposure) followed by reverberation



(c) Detail of reverberation following corona pulse (about 1 millisecond)

Figure 3 - Phenomenon of corona discharge.

THE EXPERIMENTAL PROCEDURE

The equipment was first tested in air (Figure 4) to make certain that it was operating properly and to provide a basis for comparison with subsequent readings, as it is well known that the exact shape of the Paschen curve tends to depend on the particular configuration and equipment being used. To test other gases, the bell jar was first evacuated to a pressure of 60 microns Hg; and enough gas was introduced to raise the pressure to 60 mm Hg or more—thus guaranteeing a purity of 99.9 percent in the gas being tested. After the pressure was recorded, the voltage was raised across the electrodes until breakdown was observed on the oscilloscope. The voltage was then backed off until the discharge ceased and was raised again in small increments until corona was again observed. This procedure was followed to prevent errors due to time-lag effects. For each reading the entire procedure was followed twice to make sure the reading was correct. Once the reading was obtained for a given pressure, enough gas was pumped out to lower the pressure by about 10,000 feet equivalent altitude (around 5000 feet near the minimum voltage), and the next breakdown voltage was obtained. Three runs were made for each gas, with a gapwidth between the electrodes of 1 mm, 2/3 mm, and 1/3 mm.

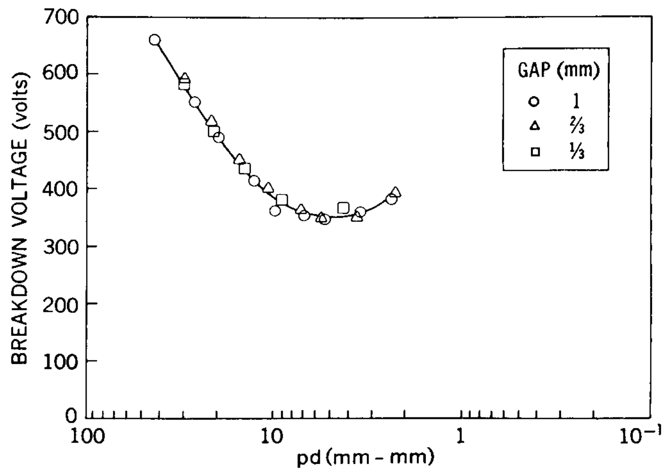


Figure 4—Paschen curve for air test.

CONCLUSIONS

The results show that the electronegative gases tested lose most of their advantage over air as insulators at lower pressures. Freon 114, which has one of the highest dielectric strengths of any of the Freons at atmospheric pressure, had the lowest minimum breakdown voltage of any of the gases tested (about 435 volts). The gas SF_6 had the highest minimum breakdown voltage (520 volts), as compared with a minimum for air of 353 volts, in the present configuration. Note that the relation between breakdown voltage and molecular weight mentioned by Camilli (Reference 11) ceases to hold for the minimum breakdown voltage.

The results of these tests, shown in Figure 5, indicate that gases of the type tested are not too promising as insulators at lower pressures in satellites. On the other hand, preliminary tests indicate that vapors of such liquids as FC-75 seem to keep their dielectric properties much better than gases at lower pressures. Two new Freon compounds currently under development, which are liquid at normal temperature and pressure, also hold promise; they are 1,1,1,3-tetrachlorofluoropropane, and 1,1,1-trichloropentafluoropropane. The former especially is claimed by the manufacturer to have a dielectric strength in vapor form 4.7 times that of FC-75. These vapors would seem to merit further investigation.

ACKNOWLEDGMENTS

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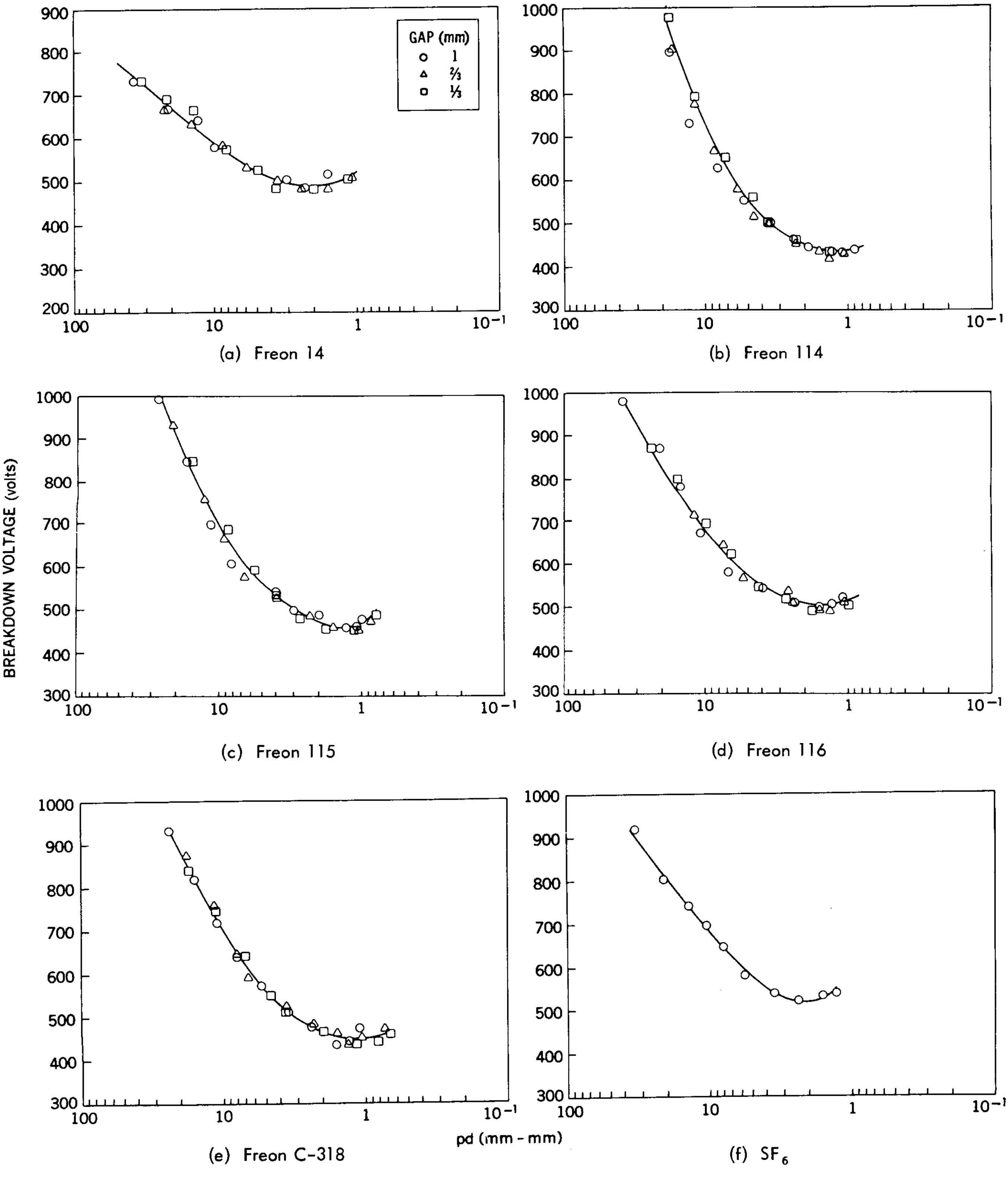

Figure 5 - Paschen curves for Freon gases and SF_6.

Coyner of E. I. Du Pont de Nemours and Company, who supplied the Freon gases used and who gave generously of his time and counsel.

Last but not least, the author would like to express his appreciation for the assistance given him by the many technicians and machinists of the Goddard Space Flight Center, without whose assistance this work would not have been possible.

REFERENCES

1. Meek, J. M., and Craggs, J. D., "Electrical Breakdown of Gases," Oxford: Clarendon Press, 1953.
2. Devins, J. C., and Sharbaugh, A. H., "The Fundamental Nature of Electrical Breakdown," *Electro. Tech.* 67(2):104-122, February 1961.
3. Pollack, H. D., and Cooper, F. S., "The Effect of Pressure on the Positive Point-to-Plane Discharge in N_2, O_2, CO_2, SO_2, SF_6, CCl_2F_2, A, He, and H_2," *Phys. Rev.* 56(2):170-175, July 15, 1939.
4. Camilli, G., and Chapman, J. J., "Gaseous Insulation for High-Voltage Apparatus," *Trans. Amer. Inst. Elect. Engrs.* 66:1463-1470, 1947.
5. Wilson, W. A., Simons, J. H., and Brice, T. J., "The Dielectric Strength of Gaseous Fluorocarbons," *J. Appl. Phys.* 21(3):203-205, March 1950.
6. Camilli, G., and Plump, R. E., "Fluorine-Containing Gaseous Dielectrics," *Trans. Amer. Inst. Elect. Engrs.* 72, Pt. 1 *(Comm. and Electronics)* No. 6:93-102, May 1953.
7. Geballe, R., and Reeves, M. L., "A Condition on Uniform Field Breakdown in Electron-Attaching Gases," *Phys. Rev.* 92(4):867-868, November 15, 1953.
8. Berberich, L. J., Works, C. N., and Lindsay, E. W., "Electric Breakdown of Perfluorocarbon Vapors and Their Mixtures With Nitrogen," *Trans. Amer. Inst. Elect. Engrs.* 74, Pt. 1 *(Comm. and Electronics)* No. 21:660-666, November 1955.
9. Camilli, G., Liao, T. W., and Plump, R. E., "The Dielectric Behavior of Some Fluorogases and Their Mixtures," *Trans. Amer. Inst. Elect. Engrs.* 74, Pt. 1 *(Comm. and Electronics)* No. 21:637-641, November 1955.
10. Narbut, P., Berg, D., et al., "Factors Controlling Electric Strength of Gaseous Insulation," *Trans. Amer. Inst. Elect. Engrs.* 78, Pt. 3 *(Power Apparatus and Systems)* No. 43:545-551, August, 1959.
11. Camilli, G., "Gas-Insulated Power Transformers," *Proc. Inst. Elect. Engrs.* 107A(34):375-382, August 1960.
12. Blodgett, F. W., "Properties of Octafluorocyclobutane, a Dielectric Gas," *Trans. Amer. Inst. Elect. Engrs.* 78, Pt. 1 *(Comm. and Electronics)* No. 41:63-66, March 1959.
13. Reuther, H.,"Fluorkarbone als Elektrische Isolierstoffe," *Elektrie* 15(6):184-186, June 1961.

14. "Bibliography on Gaseous Dielectric Phenomena", *Amer. Inst. Elect. Engrs. Spec. Publ.* S-97, April 1957.

15. Dakin, T. W., and Lim, J., "Corona Measurement and Interpretation," *Trans. Amer. Inst. Elect. Engrs.* 76, Pt. 3 *(Power Apparatus and Systems)* No. 33:1059-1065, December 1957.

NASA-Langley, 1963 G-353